Temporal Variability in CH_4 Fluxes from a Northern Forest Ecosystem

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Abstract.

Atmospheric CH4 fluxes were calculated using the Modified Bowen Ratio (MBR) method for the Chequamegon Ecosystem of northern Wisconsin for 1997-1999. Diurnal variability was observed in the gradients of CH4 and CO2 and in CO2 flux, and the MBR method was considered valid for >95% of the hourly data. MBR fluxes of CH4 increased in magnitude during the day; however, fluxes were neither positive or negative on a given day. Plotting the covariance between CH4 fluxes and air temperature suggests that peak CH4 fluxes lag behind in air temperature by ~ 8 days. In all years, deposition of CH4 started in early April and continued through June. Maximum rates of deposition occurred during 1998 and 1999 (~0.7 mg m-2 h-1 d-1). During 1997 deposition occurred at a lesser rate and ended earlier. CH4 fluxes increased at a rate of 0.85 mg m-2 h-1 d-1 from early July to mid-September during the years of 1997 and 1998 (1999 data missing). Absolute values of total emission or deposition for a given year are uncertain due to periods of missing data, but likely range between -2.6 to 5.3 x 10^5 mg m-2 annually.

Why Study CH4?

CH4 is a greenhouse gas with a global warming potential that is ~55 times that of CO2. Natural wetlands are estimated to contribute up to 25% of the annual emission of CH4 to the atmosphere, yet many wetland environments have not been quantified for CH4 emissions (e.g., the contribution of northern wetlands is uncertain). Upland regions have been sited as sources and sinks of atmospheric CH4, and in the mixed forests containing both wetland and upland areas, such as in this study, each ecosystem contributes to the net annual gain or release.

What is ChEAS? (the Chequamegon Ecosystem-Atmosphere Study)

ChEAS is a multi-organizational research effort studying biosphere / atmosphere interactions within a mixed forest in Northern Wisconsin. The ChEAS research site is one of many in the Ameriflux and FLUXNET networks (Figure 1). The goals of these groups are to obtain long-term measurements of CO2, water, and energy exchange from a variety of ecosystems in order to define the current global CO2 budget, and enable improved predictions of future concentrations of atmospheric CO2.

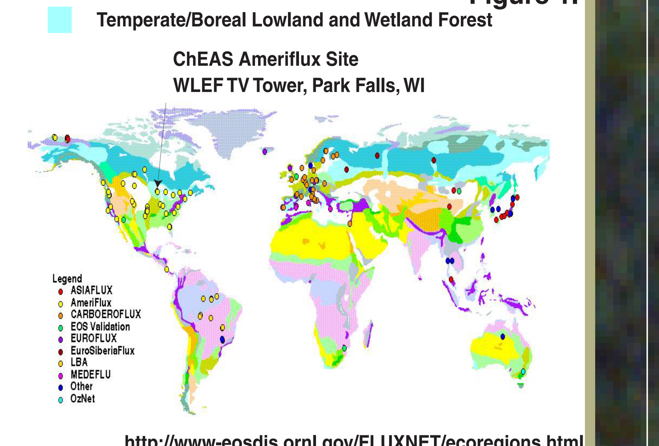
ChEAS Objectives:

- Understand the processes controlling forest-atmosphere exchange of carbon
- Bridge the gap between canopy-scale measurements and regional scale ecosystem dynamics
- Study boundary layer dynamics

Objective of this Study:

- Establish the magnitude of CH4 emission / deposition over a forest ecosystem
- Evaluate the temporal variability of sources and sinks of CH4 (diurnal, seasonal, interannual)
- Assess the correlation of CH4 fluxes with environmental factors (temperature, water levels, etc.) over multiple years

Figure 1.



http://www-eosdis.ornl.gov/FLUXNET/ecoregions.html

The Study Area.

The Chequamegon-Nicolet National Forest (Figure 2) covers an area approximately 325,000 ha, and the dominant forest types are mixed northern hardwoods (85,000 ha), aspen (75,000 ha), and lowlands and wetlands (60,000 ha). Much of the area was logged, mainly for pine, during 1860-1920 and has since regrown. Human population density in the area is very sparse, approximately 5 people per square kilometer. The climate is cool continental, with a mean annual temperature of 4.1 C (-12.9 in January, 18.9 in July), and an average precipitation of 80 mm.

Source: http://cheas.umn.edu/cheas_ftp/

Figure 2. View from WLEF tower.

Data Collection.

- Instruments mounted on WLEF TV tower, 447 m (Figure 3)
- Continuous data collection of:
- CO2 fluxes measured at 30, 122, and 396 m
- CO2 concentrations measured at 11, 30, 76, 122, 244, and 396 m
- CH4 concentrations measured at 30, 76, and 396 m (hourly)

- CO2 concentrations measured using LI-COR infrared gas analyzers
- CH4 concentrations measured using gas chromatography
- CO2 fluxes calculated using eddy covariance method, using 3D sonic anemometers to measure wind velocities

- CH4 fluxes calculated using the Modified Bowen Ratio method (next panel)

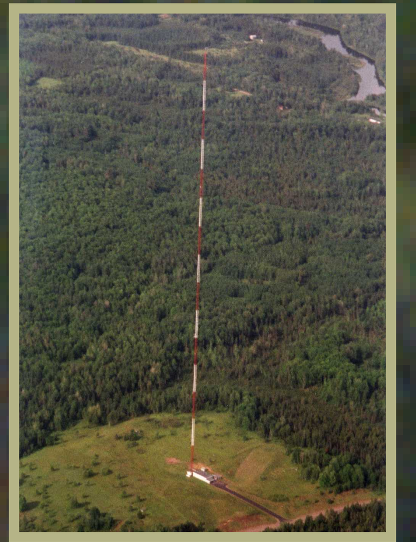


Figure 3. View of WLEF tower.

Calculating CH4 Fluxes.

Modified Bowen Ratio Technique.

During a period of horizontally homogeneous conditions, the vertical flux of a constituent is related to the vertical gradient through parameter K, the eddy diffusivity or exchange coefficient. In many studies, K is assumed to be constant for a give set of flow conditions. Because we have measured both the flux and gradient of CO2, we can compute K_{CO2}. Using the Modified Bowen Ratio technique, we assume $K_{CO2} = K_{CH4}$, which states that the turbulence mixes and transports CO2 and CH4 indiscriminately, and can calculate the CH4 flux from the gradient of CH4 (see right). Typically, the MBR approach is thought to be valid for meteorological conditions that occur close to the ground.

The gradient transport or K-theroy predicts:

$$F_{CH_4} = K_{CH_4} \times \frac{\delta CH_4}{\delta z} \quad \text{and} \quad F_{CO_2} = K_{CO_2} \times \frac{\delta CO_2}{\delta z}$$

$$\text{if} \quad K_{CO_2} = K_{CH_4}, \quad \text{then} \quad \boxed{F_{CH_4} = F_{CO_2} \times \frac{\delta CH_4}{\delta CO_2}}$$

Diurnal Variability of Gradients and Fluxes.

- Mean hourly CH4 and CO2 gradients and fluxes are strongest during the summer months (Figure 4)
- Mean hourly CH4 and CO2 gradients build during the night, and drop nearly to zero during the day
- CO2 flux is slightly positive due to respiration during the night, and negative during day due to photosynthesis during summer.
- Calculated CH4 fluxes show less variability during the night, and more during the day, and are not consistently positive or negative.

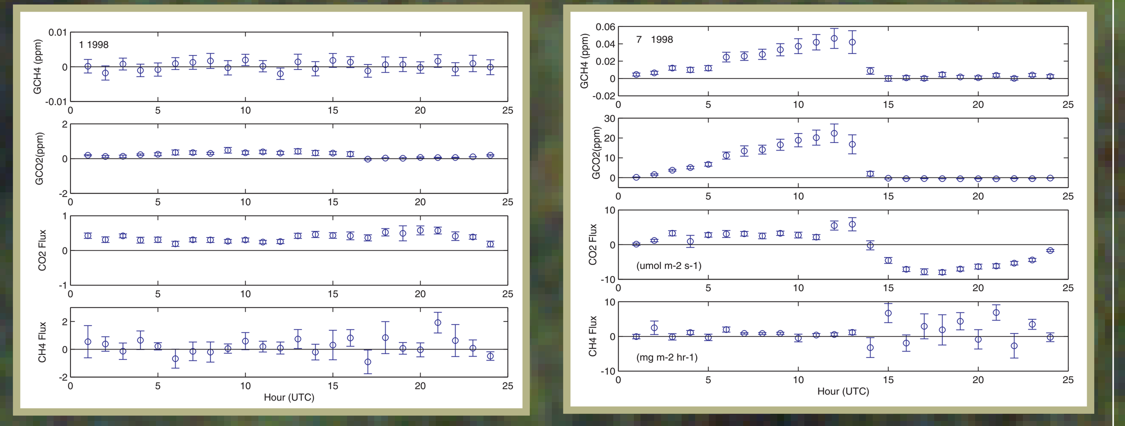


Figure 4. Mean hourly CH4 and CO2 gradients and CO2 fluxes and the calculated CH4 fluxes using the modified bowen ratio method for January and July, 1998. Error bars indicate the standard error.

Removing Outliers.

Spurious high values (positive or negative) of hourly CH4 fluxes could have a large influence on calculated daily or monthly means.

Several methods were tested to detect and remove any outliers in the calculated CH fluxes:

1) Histograms of calculated fluxes showed normally distributed data, a few outliers observed (not shown)
2) Relationship between K and CH4 flux not observed ('counter-gradient' flow did not produce anomalous CH4 flux)
3) Outliers were a result of when the flux of CO2 was high while the ratio of the CH4 to CO2 gradients was low, or vise versa (Figure 5).

Final Constraints:

1) u* > 0.23 (u*<0.23 means low mech. turbulence, and unreliable CO2 flux)
2) Abs (CH4 Gradient / CO2 Gradient) <0.15
3) Abs (CO2 flux) < 100 umol m-2 s-1

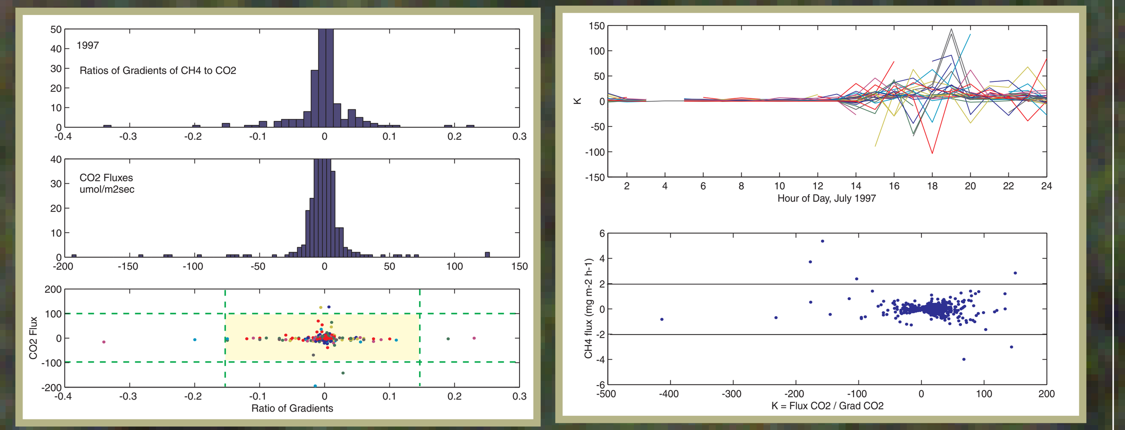


Figure 5. The plots above show how the constraints were chosen for anomalous flux. Histograms of ratio of the CH4 to CO2 gradients and CO2 fluxes are shown for 1997, and the area of shown in yellow in the third plot indicates the region of non-outliers. On the right, the diurnal cycle of K is shown for July, 1997, and the bottom plot shows how large positive or negative K does not correlate with anomalous CH4 flux.

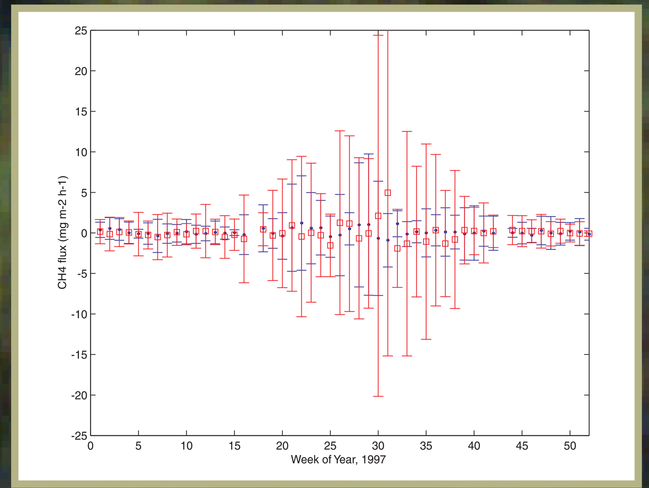
Do Average Daytime Fluxes differ from Average Nighttime?

The question arose if certain hours of the day are not representative for calculation of the mean daily or weekly CH4 flux, or if average daily fluxes differ from average nightly.

A t-test of daily vs. nightly means was conducted on all three years of data, and at a 95% confidence, only 3 days showed significantly different means.

Reducing the confidence to 10%, thereby making it easier to reject that the means are the same, the test suggested that 25% of the daily and nightly means were different.

In computing mean values, the no hourly data was eliminated based on time of day of sampling.



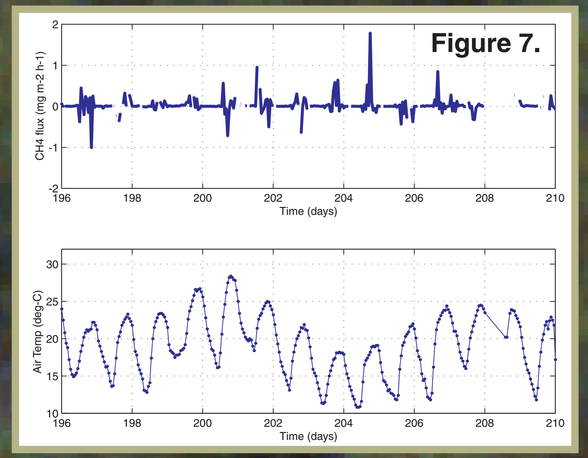
Diurnal Variability.

Time Series (Figure 7).

- Individual hourly CH4 fluxes are low during the night. Starting at ~sunrise, fluxes increase in magnitude, but are not consistently positive or negative. Further research is necessary to determine why hourly measurements during the day differ from during the night. Variability is likely related to either changes in meteorological conditions (e.g., Roulet et al., 1997), or possibly changes in CH4 production.

- CH4 production is highly dependent on soil temperatures, which are not yet available. In Figure 7, the dirunal variability of air temperature is plotted.

Figure 7.



Covariance of CH4 fluxes and Air temperature (Figure 8).

- Diurnal variability in both time series in Figure 7 produces a diurnal signal of covariance.
- The maximum covariance suggests that CH4 fluxes lag maximum air temperatures by ~ 8 days.

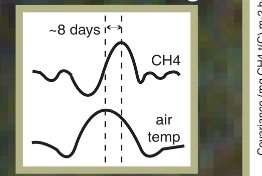
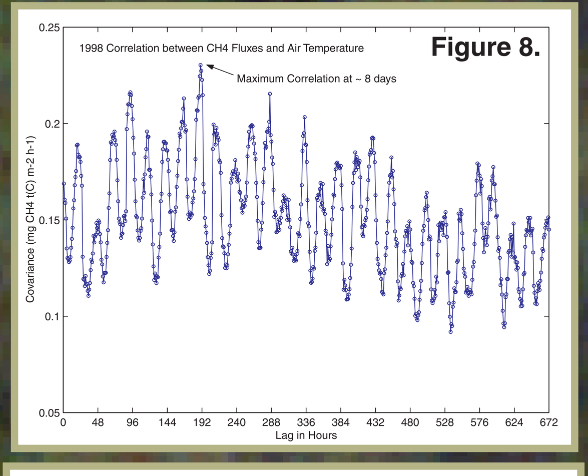


Figure 8.



Seasonal Variability / CH4 Flux Envelope.

- In Figure 9, the weekly means track each other fairly well until week 15 (~ April 15), all years.
- Spring deposition strongest in 1998-99. 1997 displays positive or net zero flux in spring.
- Fluxes increase in week 25, positive fluxes were observed each year during week 27 (~early-mid July)
- Deposition was observed during after week 32 (mid-August) for multiple years; however, positive fluxes were also observed for some years between weeks 32-39.

Year	Min.	Week	Max	Week
1997	-1.8	32-37	4	31
1998	-3.8	22	2.2	26
1999	-2.1	20	3	34

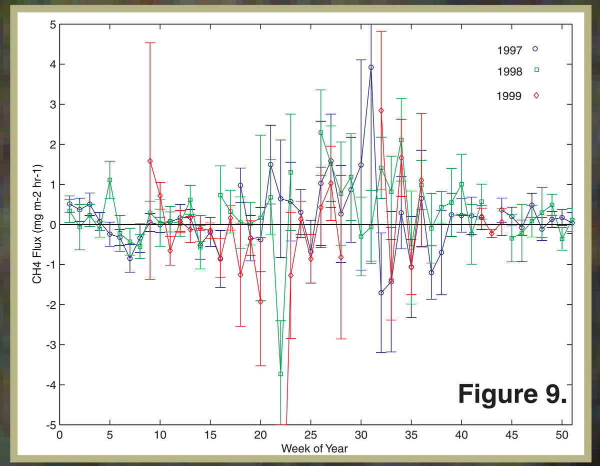


Figure 9.

Cumulative Flux.

Deposition.

- In Figure 10, the rate of deposition in 1999 and 1998 was ~0.71 (mg m-2 h-1)/day or 17 mg m-2 d-2. The depositional period seemed to last longer in 1999 than in 1998; however, 1998 data are missing during this time.
- Rate of deposition during spring 1997 is less, and ends earlier.

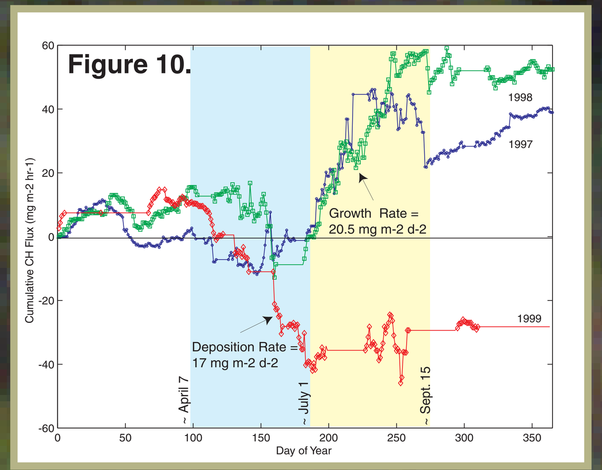
Emission.

- 1997 and 1998 emissions increase at a rate of ~0.85 (mg m-2 h-1)/day or 20.5 mg m-2 d-2 starting approximately July 1 and ending in mid-September.
- 1999 data missing during the period of peak emission rates.

Yearly totals.

Absolute totals can not be calculated for any given year due to missing data. However, the three years of data suggest that yearly totals are likely between -30 and 60 mg m-2 hr-1, or between -2.6 to 5.3 x 10^5mg m-2 over the period of a year.

Figure 10.



Results Seem Consistent with Other Studies:

Study	Environment	Method	Observations (all values in mg m-2 h-1)
Crill, 1991	Temperate Woodland Soil	Chamber	Net uptake, max ~0.2 in April
Simpson et al., 97	Boreal Aspen Forest	Micromet	Emission starts ~6/1, max. 0.13 in Aug.
Roulet et al., 97	Boreal Beaver Pond	Micromet	Emitted 5-9/94, max. 7.5 mid Aug., daily highs
Shurpali & Verma,98	Minnesota Peatland /Fen	Micromet	Emitted 5-10/91,92, max. 6-8 7/91 and 8/92

Further Work Needed to Address Correlation of CH4 Fluxes with Soil Temperature, Water Level Table, and Wind Direction.

Acknowledgements.

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